Guideline for Agricultural Water Management Data Collection: NATIONAL STANDARD

Ethiopian Institute of Agricultural Research (EIAR)

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Foreword

I am happy to share this guideline for standardizing agricultural water management (AWM) data developed by national experts from Hawassa University and research and development organizations, with the facilitation of the Coalition of the Willing (CoW) and GIZ. The Ethiopian Institute of Agricultural Research (EIAR) deeply values the commitment and collaboration that have led to the realization of this initiative.

The EIAR acknowledges the importance of this guideline as part of a series of data standardization guidelines developed with the facilitation of the CoW. These guidelines result from extensive collaboration among experts in agricultural water management, soil science, agronomy, data science, and information technology. The publication and active use of three of these guidelines, including by the EIAR, underscore their crucial role in supporting the national digital agricultural roadmap and promoting digital agricultural transformation in the country. Establishing a centralized database system based on the Findability, Accessibility, Interoperability, and Reusability (FAIR) data principles ensures a robust agricultural data infrastructure, ready to support the digital agricultural transformation effort.

This AWM guideline emphasizes irrigation, drainage, and water quality, offering detailed instructions on parameters, measurement techniques, and reporting standards. This cohesive approach ensures seamless data integration, storage, sharing, and streamlined analysis. As a result, it facilitates better-informed and more effective AWM decisions, contributing to the creation of a national agricultural data hub.

Along with previous initiatives, the AWM guideline is an excellent model for other agricultural research sectors. It exemplifies a structured approach to data standardization and highlights the collaborative efforts of experts from various fields. This ensures the development of a coherent and integrated system for data generation, storage, and sharing.

The EIAR will integrate this guideline within the institute and support its widespread use in the national agricultural research system. On behalf of the EIAR, I would like to express my sincere gratitude to all the contributors and reviewers who have devoted their time and expertise to this initiative. Your insights and commitment have been invaluable in shaping a resource that will significantly enhance our efforts to standardize data. We believe that this guideline will be a vital tool for researchers, practitioners, and policymakers, empowering them to harness the potential of data in agricultural water management.

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Preface

In the fields of natural resource management, including soil science, agronomy, and agricultural water management, it is crucial to ensure the quality and consistency of data. Recognizing this need, the Coalition of the Willing (CoW), a group of dedicated individuals and institutions established in 2018, has been leading efforts to promote data sharing and standardization within these disciplines.

The CoW has spearheaded the development of several critical guidelines, including those for Agronomy and Soil Fertility; Soil Biology; Laboratory Analysis for Soil, Water, and Fertilizer; Soil Survey and Characterization; and Watershed Management. These guidelines are a direct result of these efforts and represent a significant step toward the development of a centralized database system that adheres to the FAIR (Findability, Accessibility, Interoperability, and Reusability) data principles. In the realm of agriculture, the importance of water management cannot be overstated. The standardization of data in agricultural water management is a crucial step toward optimizing resource usage, enhancing crop productivity, and ensuring sustainability. By establishing uniform formats and protocols for collecting, storing, and analyzing water-related data, stakeholders can make informed decisions and implement efficient agricultural water management practices.

This guideline for agricultural water management focuses on irrigation and drainage. It outlines the minimum parameters that need to be measured, the methods to be used, and the reporting requirements for agricultural water management. Detailed methods and approaches for each parameter are referenced, ensuring that practitioners have access to the comprehensive information necessary to implement the guideline effectively.

This guideline is a result of extensive collaboration among experts in agricultural water management, soil science, agronomy, data science, and information technology. It offers a comprehensive framework that addresses data standardization's unique challenges and requirements in agricultural water management. Key topics covered include data formats, nomenclature, data cleansing, metadata management, and data recording and reporting protocols.

The CoW taskforce is extremely grateful to all the contributors and reviewers who have generously dedicated their time and expertise to this initiative. Their insights and commitment have been invaluable in shaping a resource that will significantly advance our efforts in standardizing data. We believe that this guideline will be a valuable tool for researchers, practitioners, and policymakers that will enable them to leverage the potential of data in agricultural water management.

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Introduction

Increasing food production and agricultural products in Ethiopia requires updated, high-quality, and robust data. These require the transformation and intensification of the agricultural sector with information generated from dependable data. Acquiring dependable data on agricultural water management (AWM) can be achieved sustainably through the development of land and water resources. Standardized data generated from dependable sources using acceptable methods and procedures contributes to the digital transformation of the country's agricultural sector.

The current data standardization guideline for agricultural water management (excluding *rainfed agriculture*) ensures that data collected from research and development work can easily be shared among stakeholders. This standard prescribes the minimum data required in AWM, the accompanying metadata, the methodology followed, and the reporting protocols required in data acquisition and communication under laboratory and field conditions.

This guideline focuses on the following five parts: irrigation water source and field-level flow; irrigation and drainage water quality; irrigation agronomic data; irrigation system evaluation; and, finally, agricultural drainage water management.

Data generators, data managers, and data users in universities, research institutes, and development institutes are the primary users of this guideline. The guideline represents a significant advancement in agricultural water management, particularly within the water sector, and the digitization of Ethiopia's agricultural sector. It is important to note that this guideline is not to be used in isolation but in conjunction with standard reference manuals or standard booklets that correspond to each section of the guideline.

Rationale

Developing nationally standardized data for agricultural water management in Ethiopia is crucial to ensure consistent data collection methods and formats across different regions and organizations, which enhances the quality and reliability of the data. Having consistent standards makes the data more valuable for decision-making, thus enabling easy comparison and analysis of information from various sources.

A standardized process decreases duplication of efforts and streamlines data management, saving time and resources by eliminating the need to reformat or reconcile data. It also facilitates data sharing and integration among different agencies, thus providing policymakers with accurate and timely information for effective agricultural water management.

By establishing a national standard, Ethiopia can improve data quality, promote evidence-based decision-making, and enhance water resource management practices that contribute to sustainable development through the digital transformation of the agricultural sector.

1 Sources of Water for Irrigated Agriculture

1.1 Surface Water and Groundwater Source Measurement

Nationally, it is crucial to standardize measurements of irrigation water sources. These sources might be surface water, groundwater, and the conjunctive use of treated wastewater and drainage water. Flow from these sources can be measured using structural, velocity-area, float, and dilution methods.

1.2 Parameters to Be Measured and Analyzed

In flow measurement using the structural method, the water level (head) or velocity is measured and charts, tables, or equations are used to calculate the water flow or discharge. Weirs, flumes, and orifice meters can be used to measure the head (h) or pressure (P) to determine discharge (Q). The head is measured at a prescribed distance upstream of the structure, while the downstream water level is controlled to allow free-flow or submerged-flow conditions. The main ways to measure flow are the following:

- Structural measurement (i.e., head discharge relationship or the relationship between water height and flow).
- Velocity-area method (i.e., measuring water speed at different points and depths and then calculating the flow). The average velocity, depth, and width of each vertical section are determined and the discharge per section is calculated by multiplying the mean velocity by the depth and width. The discharge values from all sections are added together and this sum represents the total discharge for the entire channel.
- The float method (i.e., timing how long it takes a floating object to travel a set distance). Velocity is calculated by dividing the length of a predetermined section by the average duration traveled by the float. This is then multiplied by the cross-sectional area (width × average depth) to estimate discharge.
- Dilution techniques (i.e., measuring how quickly a solute spreads through the water). Discharge is determined by the length (distance between the injection point and sampling point) and depth of the stream, and the time it takes the solute to cover the length of the sampling point.

1.3 Applicability

The current guideline works at all scales of irrigated fields in Ethiopia on rivers, channels, and reservoir outlets. Table 1 presents the variables/parameters that are going to be measured at the source. Unless mentioned otherwise, all date-related data are to be collected using the Gregorian calendar and space-related parameters are to be recorded in UTM projection in metric units.

Table 1. Irrigation water flow measurement standards

Metadata	Project description [number of beneficiaries; actual irrigated area in ha]:			
	Name of scheme:			
	Year of commissioning [Gregorian calendar]:			
	Water source: [river diversion/lake/storage dam/pumped] with name:			
	Scheme size in ha:			
	Scheme owner [public, cooperative, private]:			
	Northing (UTM): Easting (UTM): Altitude (masl):			
Parameter[1]	**Description**	**Method**	**Recording protocol**	**Reporting unit**
Discharge [Q]	Calculated discharge $$Q = \left(\frac{2}{3}\right)^{\frac{3}{2}} b\sqrt{(g)}H^{\frac{3}{2}}$$	Broad-crested weir [measurement of *H* is head above the crest in meters and *b* is the bed width in meters]	Field and desk	m^3/s
	Calculated discharge $$Q = \left(\frac{2}{3}\right)^{\frac{3}{2}} C_d C_v b\sqrt{g}h^{\frac{3}{2}}$$ $$C_d = \left(1 - \frac{0.006L}{b}\right)\left(1 - \frac{0.003L}{h}\right)^{\frac{3}{2}}$$	Rectangular-throated flume, for Cv; refer to the standard table [measurement of *h* is head above the throttle flume in meters, *L* is the throttle flume length in meters, and *b* is the bed width in meters]	Field	m^3/s

Continues ▶

1. Details on discharge measurement procedure are found in Raghunath (2006). Hydrology: Principles, Analysis and Design. New Age International (P) Limited, New Delhi, India.

Parameter	Description	Method	Recording protocol	Reporting unit
Discharge [Q]	Calculated discharge $Q = 1.73bh^{\frac{3}{2}}$; *h* is measurement of head above the weir in meters	Rectangular notch thin plate weir, contracted	Field and desk	m^3/s
	Calculated discharge; $Q = 1.766\,(1 + 0.15h/p)\,bh^{\frac{3}{2}}$ *p* is hump height, *b* is bed width, and *h* is head over the hump	Rectangular notch thin plate full-width	Field and desk	m^3/s
	Calculated discharge $Q = 1.365h^{\frac{5}{2}}$	Triangular (v-notch, 90°)	Field and desk	m^3/s
	Calculated discharge $Q = 0.682h^{\frac{5}{2}}$	Triangular (v-notch, 45°)	Field and desk	m^3/s
	Calculated discharge $Q = 0.347h^{\frac{5}{2}}$	Triangular (v-notch, 22.5°)	Field and desk	m^3/s
	Calculated discharge $Q = \left(\frac{2}{3}\right)^{\frac{3}{2}} C_d C_v b \sqrt{g} h^{\frac{3}{2}}$	Rectangular-throated flume	Field and desk	m^3/s
	$Q = kh^u$ *k* is a dimensionless factor, a function of the throat width *b*, and *u* varies from 1.522 to 1.600; for details of the equations of discharge, see Annex Tables 1 and 2.	Parshall flume	Field	m^3/s
	$Q = AV$ *A* is the cross-sectional area of the channel and *V* is the flow velocity obtained from measured floating length and floating time. Note: Because surface velocities are typically higher than mean or average velocities, *V* mean = *k* * *V* surface, where *k* is a coefficient that generally ranges from 0.66 to 0.75, depending on channel depth.	Float-area method	Field	m^3/s

Parameter	Description	Method	Recording protocol	Reporting unit
Discharge [Q]	$Q = \frac{c - c_2}{c_2 - c_1} q$ where *q* = quantity of solution injected (cm^3/s), *c* = amount of salt in dosing solution (g/cm^3), c_1 = concentration of salt originally in the stream (g/cm^3), and c_2 = concentration of salt in the sample downstream (g/cm^3).	Dilution technique	Lab	cc/s
Velocity [V]	Measure velocity at *0.6-depth*	Current meter: one-point method	Field	m/s
	Velocity at *0.2-depth* and *0.8-depth* from water surface $\bar{v} = 0.5\left(v_{0.2} + v_{0.8}\right)$	Current meter: two-point method	Field	m/s
	Velocity at *0.2-depth*, *0.6-depth*, and *0.8-depth* from water surface $\bar{v} = 0.25\left(v_{0.2} + 2v_{0.6} + v_{0.8}\right)$	Current meter: three-point method	Field	m/s
Pump[2] discharge	$Q = \frac{\eta \rho g}{H}$ *p* = pump power (Watts) *H* = pump head (m) η = pump efficiency *g* = gravitational acceleration (m/s^2)		Field	m^3/s

2. Details on pump system application can be found in William and Carlos (1978). A Water Resources Technical Publication: Engineering Monograph No. 40. United States Department of the Interior Bureau of Reclamation, Denver, Colorado, USA.

2 Minimum Data Standard for Irrigation and Drainage Water Quality

2.1 Irrigation Water Quality

Not all types of water are suitable for human beings and the same applies to plants. Impurities contained in water are dangerous for plant growth and are not satisfactory for irrigation. The quality of suitable irrigation water is highly influenced by the constituents of the soil that is to be irrigated. Certain water might be harmful for irrigation on a particular soil, but the same water might be tolerable or even useful for irrigation on some other soil. The various types of impurities that make the water unfit for irrigation can be classified as follows:

- Sediment concentration in water.
- Total concentration of soluble salts in water.
- Proportion of sodium ions to other cations.
- Concentration of potentially toxic elements present in water.
- Bicarbonate concentration, which is related to the concentration of calcium plus magnesium.
- Bacterial contamination.

a. Water sampling

To test water characteristics, a sample must be properly collected, preserved, transported, identified, and analyzed.

b. Sampling methods

- To collect the sample, move into the midpoint of the stream or river and face into the direction of the flow.
- By doing so, any potential contamination from substrate disturbance will flow away from the sample being collected.
- Remove the lid of the bottle, ensuring that your fingers do not come into contact with the internal surfaces of the sample container or lid.

- Invert the sample container fully and submerge to a depth of 0.3 m below the water surface to avoid surface scum and debris coming into the water, including macrophytes.
- If the water is less than 0.6 m deep, you should collect the sample at mid water column.
- Rotate the sample container in the direction of the flow.
- If bottle rinsing is required, allow the sample to fill at least one-third of the container volume. Remove from the water and recap.
- Shake the sample container gently and pour the water downstream of the sample collection point.
- Complete the rinse procedure three times.
- Repeat the steps above and then allow the sample container to fill.
- Recap the sample container.
- Return to the shore and check that the details on the sample container are correct.
- Place the sample container in a cooler box (with ice or ice bricks) or refrigerator and chill. Double-bag samples if ice is used.
- Fill out the "chain of custody" form.

Grab sampling: a single sample collected over a very short period. Represents the conditions of the water only at one particular time and location. Not suitable for parameters that change instantly.

Composite sampling: grab samples taken at regular intervals over the sampling period. This is more appropriate to determine overall or average conditions over a certain period.

c. Sample preservation techniques

- Addition of acid to the sample to preserve dissolved metals (HNO_3 and H_2SO_4)
- Freezing
- Refrigeration at –40°C is a common preservation technique, widely used in fieldwork

d. Transportation and handling of samples

- You should transport both chemical and bacteriological samples in insulated boxes (preferably in an icebox).
- Keep at temperature from 4°C to 10°C. You can do this by packing with bags containing a freezing mixture.
- If samples cannot be cooled, you must examine them within 2 hours of sampling. If neither condition can be met, you should not analyze the samples (particularly for bacteria).
- Begin the examination of bacteriological samples within 24 hours of collection.
- For chemical analysis, you should analyze parameters that are subject to change, such as nitrate and phosphate, within 24 hours of collection.
- Clean and disinfect the box used to carry samples.
- The sampler should disinfect bottles and hands after each sampling to avoid contamination.

e. Sample identification

- You should identify all samples immediately and clearly.
- Identify samples by labeling and fill out the "chain of custody" form, which should include clear information that can be understood by others:
  - Location of sampling point
  - Date
  - Time
  - Description of sample
  - Comments relating to special conditions that might affect results

f. Sample frequency

- Sampling frequencies for raw water sources depend on
  - Their overall quality
  - Their size
  - The likelihood of contamination
  - The season of the year
- Sampling frequencies for treated water depend on
  - The quality of water sources
  - The type of treatment

g. Sampling drainage water

- When you take samples of drainage water, you should determine the temperature and pH at the time of collection.
- To ensure that all parts of the drainage system are tested, you must take samples from (1) the drain outlet, before the water enters natural waterways, and (2) at various junction points throughout the drainage network.
- Before you take the sample, you should disinfect the sampling bottles and let some water flow through to flush out any stagnant water in the drainage.

The recording and reporting protocol of the irrigation water quality parameters has paramount importance in standardizing water quality attributes (Table 2). The effect of each of these water quality parameters and methods is discussed in sections 2.2 to 2.12.

Table 2. Data collection standard format for water quality

Metadata	DS	Sampling date [Gregorian calendar]		
	DT	Testing date [Gregorian calendar]		
	Nature:	Nature of sample [grab, composite]		
	Scheme scale:	[large, medium, small]		
	Source type:	River/well/reservoir		
	Northing (UTM): Easting (UTM): Altitude (masl):			
Parameter	**Description**	**Method**	**Recording protocol**	**Reporting unit**
Sediment	Measured sediments in water	Gravimetric	Laboratory	mg/L
EC	Measured conductivity	Calibrated conductivity meter	in situ	µmhos/cm at 25°C
Turb	Measured turbidity	Calibrated turbidimeter	in situ	NTU
T	Measured temperature	Thermometer	in situ	°C
TDS	Measured total dissolved solid	Gravimetric	Laboratory	mg/L
pH	Measured pH	Calibrated pH meter	in situ	[H]
Bacteria/ pathogens	Count of total coliform group of *E. coli* bacteria in 100 mL of water sample	Membrane filter total coliform test	Laboratory	Count of total coliform
Na^+	Measured sodium ion	Spectrophotometer	Laboratory	mg/L
Ca^{2+}	Calculated $Ca^{2+} = CaH \times 0.4$			mg/L
Mg^{2+}	Calculated $Mg^{2+} = MgH \times 0.243$			mg/L
SAR	Calculated $SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}}$			No unit
SO_4^{2-}	Measured sulfate	Spectrophotometer	Laboratory	mg/L

Continues ▶

Parameter	Description	Method	Recording protocol	Reporting unit
PO_4^{3-}	Measured phosphate	Spectrophotometer	Laboratory	mg/L
NO_3^-	Measured nitrate	Spectrophotometer	Laboratory	mg/L
Trace elements	Measured trace element (refer to table in section 2.2.2)	Spectrophotometer	Laboratory	mg/L
Pesticides	Measured pesticides (refer to table in section 2.2.1)	High-performance liquid chromatography	Laboratory	mg/L

2.1.1 Sediment

The effect of sediment present in irrigation water depends on the irrigated land type. When fine sediment from water is deposited on sandy soil, fertility is improved. On the other hand, if the sediment has been derived from eroded areas, it might decrease fertility or soil permeability. Sediment in water creates trouble in irrigation canals as it increases their siltation and maintenance costs. In general, groundwater or surface water from reservoirs does not have sufficient sediment to cause any serious problems in irrigation. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.1.2 Total concentration of soluble salts

Irrigation water containing high concentrations of calcium, magnesium, sodium, and potassium salts can harm plants. Excessive salt concentration can decrease the ability of plants to absorb water through osmosis and limit soil aeration, which plants need for healthy growth. The extent of damage to plant growth depends on salt accumulation over time. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.1.3 Proportion of sodium ions to other cations

Most soils contain calcium and magnesium ions and small quantities of sodium ions. Usually, sodium ions are less than 5% of exchangeable cations; but, if this increases to 10% or more, the soil structure degrades. It becomes less permeable and harder to work, forms a crust when dry, and becomes more alkaline.

Sodium in soil can be measured using the sodium-absorption ratio (SAR), which indicates potential sodium-related water hazards. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

SAR is defined as $SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}}$

where the concentration of the ions is expressed in equivalent per million (epm). The epm is obtained by dividing the concentration of salt in mg/L or ppm by its combining weight (i.e., atomic wt. + valence).

2.1.4 Concentration of potentially toxic elements

A large number of elements such as boron and selenium might be toxic to plants. Traces of boron are essential to plant growth, but its concentration above 0.3 ppm might prove toxic to certain plants. Any concentration above 0.5 ppm is dangerous to nuts, citrus fruits, and deciduous fruits. Cotton, cereals, and certain truck crops are moderately tolerant of boron, whereas dates, beets, and asparagus are quite tolerant.

Even for the most tolerant crops, boron concentration should not exceed 4 ppm. Boron is usually present in various soaps. Wastewater containing soap and the like should therefore be used with great care in irrigation. Selenium, even in low concentrations, is toxic and must be avoided.

Data must be collected on potential toxic elements in irrigation water (i.e., aluminum, arsenic, beryllium, boron, cadmium, chromium, cobalt, copper, fluoride, iron, lead, lithium, manganese, molybdenum, nickel, selenium, vanadium, and zinc). The measurement method and reporting units are the spectrophotometer and milligrams per liter (mg/L), respectively. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.1.5 Bicarbonates as related to concentration of calcium and magnesium

High concentrations of bicarbonate ions might result in the precipitation of calcium and magnesium bicarbonate from the soil solution, thus increasing the relative proportion of sodium ions and causing sodium hazards. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.1.6 Bacterial contamination

Bacterial contamination of irrigation water is not a serious problem unless crops irrigated with highly contaminated water are consumed raw. Cash crops such as cotton and nursery stock, which are processed after harvesting, can therefore use contaminated wastewater without any trouble. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.2 Drainage Water Quality

Both surface and subsurface drainage effluent contain potential pollutants. These pollutants might originate from agrochemicals such as pesticides, herbicides, fertilizers, and soluble salts from leached material.

2.2.1 Pesticides, herbicides, and fungicides

Drainage water from agricultural land can contain various types of pesticides, making it challenging to assess their impacts on water quality. Most of these agrochemicals (Table 3) are synthetic organic compounds and there have been documented cases in which organic pesticides in irrigation runoff have negatively affected downstream water quality. Problems with agrochemicals are the result of farming practices, not the design or operation of the drainage system. Drainage from irrigated fields might have high concentrations of pesticides, fungicides, and herbicides, but these elevated concentrations typically occur for relatively short periods. The best solution to this problem is to improve irrigation water management and pesticide use practices.

Table 3. List of pesticides, herbicides, and fungicides considered

Compounds to measure	Method of measurement	Reporting units
Polychlorinated biphenyls (PCBs)	Chromatographic/mass spectrometric	µg/L
Polynuclear aromatic hydrocarbons	Chromatographic/mass spectrometric	µg/L
Nitrosamines	Chromatographic/mass spectrometric	µg/L
Carbamate pesticides	Chromatographic/mass spectrometric	µg/L
Organochlorine pesticides	Chromatographic	µg/L
Acidic herbicide compounds	Gas chromatographic	µg/L
Glyphosate herbicide	Gas chromatographic	µg/L
Tributyl tin	Chromatographic	µg/L
Pharmaceuticals and personal care products	Liquid chromatographic	µg/L

For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.2.2 Toxic trace elements

Inorganic trace elements are different from synthetic organic compounds (pesticides) in that they are commonly present at low concentrations in nature and a natural amount of tolerance already exists [refer Table C]. There is, however, a fine division between natural tolerance and toxicity. It is therefore essential to have good information on the concentration of trace elements in drainage water to develop safe reuse and disposal methods. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.2.3 Nutrients

The two major nutrients in drainage water are nitrogen and phosphorus. Both contribute to the eutrophication of surface waters. Nitrogen can be in an organic form (ammonium) or inorganic form (nitrate). The predominant form in surface drainage is organic N. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.2.4 Temperature

Higher temperatures occur where irrigated fields or wetlands are warmed by the sun, and tailwater from these areas is then discharged into a stream, thus increasing its temperature. This problem is often aggravated where diversions for irrigation and wetland management also diminish the total stream flow. Power plants can also affect the temperature of downstream waters. Increased temperatures have a direct effect on stream aquatic life, especially in certain cold-water streams or those with anadromous fisheries. Temperature surveys should be an essential component of any surface-water monitoring if elevated water temperatures are expected. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

2.2.5 Sulfurous compounds

Drainage of sulfuric or acid sulfate soils, predominantly found in tropical river deltas, leads to water quality problems. Improved drainage increases the discharge of acidic water, potentially releasing high quantities of sulfuric acid into nearby water bodies. This also lowers the pH, which can harm aquatic life. These soils might also release iron and aluminum, thus posing health risks if the affected water is used for drinking. For sampling and measurement procedures, refer to Rice and Bridgewater (2012).

3 Minimum Standard for Irrigation Agronomic Data

3.1 Introduction

Irrigation systems consist of two basic elements: (1) the transport of water from its source to the field and (2) the distribution of transported water to crops in the field. Soil properties and qualities are important to the design, operation, and management of irrigation systems, including water holding capacity, soil intake characteristics, permeability, soil condition, organic matter, slope, water table depth, soil erodibility, chemical properties, salinity, sodicity, and pH (USDA-NRCS, 1997). Certain soils are unsuitable for irrigation because of physical limitations, such as low infiltration rates (slow water absorption) and poor internal drainage, which might lead to salt buildup. The sustainability of irrigation as a management practice that does not cause long-term damage to soil or water resources depends on the soil's chemical properties and the quantity and quality of available irrigation water (Franzen et al., 1996; Seelig et al., 1991).

Failure to provide information needed for land classification for irrigation is usually due to an unwise decision on the required intensity of the survey; inadequate recognition of the changes that result from irrigation or drainage; inadequate attention to specific soil characteristics, particularly those associated with soil moisture; inadequate depths of sampling; failure to establish the required parameters of the survey in consultation with other specialists; and failure to interpret the soil survey finding by other specialists (FAO, 1986). Addressing the aforementioned concerns when providing information minimizes redundant data collection efforts, improves data quality, and increases confidence in using existing data.

3.2 Surface Irrigation Application

Surface irrigation dominates global irrigation practices, including in Ethiopia, accounting for 95% of all irrigation systems (Lehrsch et al., 2005). Although it is relatively less efficient than pressurized methods, the system remains widespread because of its simplicity and suitability for farmers with little knowledge of irrigation. Basin, border, and furrow are all surface irrigation methods, and the selection depends on the crop, cultivation practices, soils, topography, and farmer preferences (Table 4).

Furrow irrigation is the most widely used method for row crops and is the most misunderstood of all surface irrigation techniques. It is usually practiced on gentle slopes with a maximum gradient of 2% in arid climates and 0.3% in humid areas to mitigate erosion during heavy rainfall.

From a farming point of view, longer furrows are preferred to decrease irrigation and drainage costs in facilitating mechanization. Key parameters to be considered include furrow length, spacing, inflow rate, slope, soil type, irrigation depth, and land topography. A detailed description of the parameters, along with the system's name, location, and type, will help users visualize the entire system better.

Table 4. Data collection sheet to describe the scheme

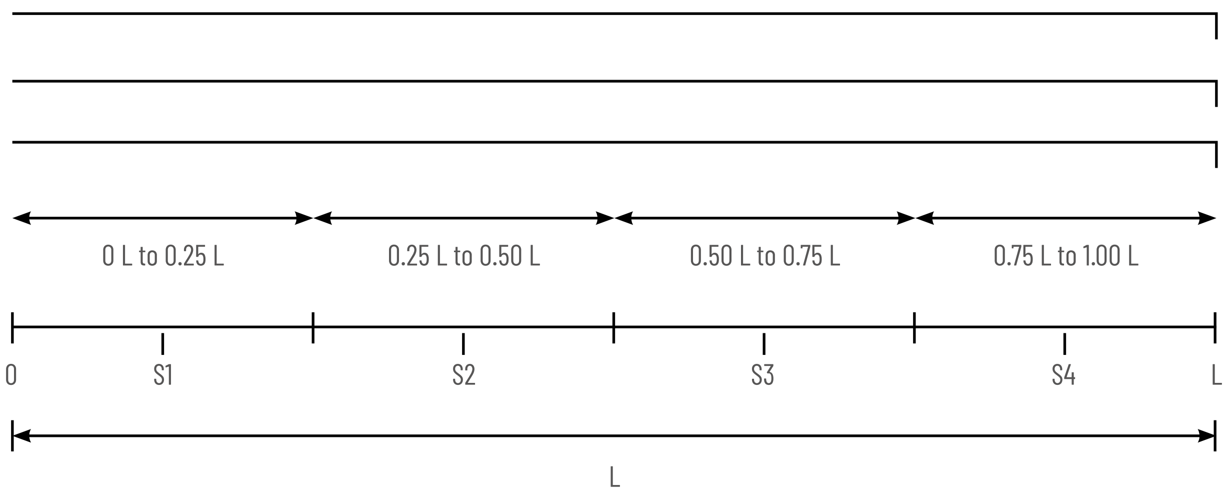
Irrigation method	Project description: Name of scheme:					
	Location [UTM] (x: y:) Altitude [masl] :)					
	Year of commissioning (GC):					
	Scheme size (ha):					
	Water source: groundwater, storage dam, diversion, pumped					
	Scheme owner: community, cooperative, private/investor:					
	Length (m)	**Spacing (1) (m)/width (2) (m)**	**Bund /levee height (m)**	**Width of bund (m)**	**Inflow rate (L/s)**	**Drain/out-flow (L/s)**
Furrow	X	1			x	X
Border	X	2	x	x	x	X
Basin	X	2	x	x	x	X

Note: x refers to the data to be collected.

Soil sampling for soil physicochemical property analysis

- **Sampling time:** You should take soil samples less than 24 hours before irrigation. Based on the soil type, you must take the sample 24 hours, 48 hours, and 72 hours after irrigation.
- **Sampling sites:** You should take samples from at least four points: from the upstream end to the tail end of the stream as indicated in Figure 1.

Figure 1. Soil sampling points along the furrow length



- **Sampling depth:** You should take soil samples at 20-cm intervals from the soil surface to the maximum root depth of the cultivated crops using an auger and core sampler.
- **Criteria of sample site:** This depends on the homogeneity and length of the furrow, border, and basin. Taking samples from more sites improves the quality of the information to be generated.
- **Sample handling**: You should take soil samples based on the soil survey protocol for irrigation (FAO, 1975)
- You should calibrate soil moisture measurement methods against gravimetric techniques.

Performance indicators for irrigation systems are used to assess the efficiency and effectiveness of water distribution for agriculture. Soil physical properties play a crucial role in determining irrigation performance. Soil samples can be taken from an irrigated field using Table 5.

Table 5. Soil physicochemical property data to be collected

MD	Measurement date			
Nature	Crop type, soil			
Source	Water application methods (furrow, ...)			
Location	Northing [UTM]	Easting [UTM]	Altitude [masl]	
Parameter	**Description**	**Method**	**Recording protocol**	**Reporting unit**
Soil texture	Measured at mid-depth of 20-cm interval from surface to maximum root depth of the crop	Hydrometer, sieve analysis, and USDA textural class	Field	Soil type
Bulk density	Calculated: $\rho = Ws/Vs(gm/cc)$	Core sampler gravimetric*	Field	g/cc

Continues

Parameter	Description	Method	Recording protocol	Reporting unit
Soil moisture	Measured (FC, PWP)	Pressure plate apparatus	Field	Vol%
Soil chemical property	Measured pH	pH meter	Field	
	Measured Ece	EC meter	Field	ds/m

Note: Soil moisture content is determined using in situ moisture sensors such as a tension meter (TDR), wetting front detector, or neutron probe, any of which should be calibrated against the gravimetric method.

3.3 Field Water Application Measurements

Key soil parameters (infiltration rate, water holding capacity, and bulk density) are crucial for effective water management assessments. Soil infiltration rate is used to determine moisture storage in the root zone, which is vital for calculating application and storage efficiency. The two most common methods to measure infiltration rate are (1) infiltrometer measurements and (2) water balance approaches. Table 6 lists the necessary data for both methods.

Table 6. Data collected to determine the soil infiltration rate

MD	Measurement date			
Nature	Soil type, slope			
Source	Water application methods (furrow, ...)			
Location	Northing [UTM] :	Easting [UTM] :	Altitude [masl] :	
Parameter	**Description**	**Method**	**Recording protocol**	**Reporting unit**
Basic soil infiltration rate	Measured (water level drop in inner ring)	Cylindrical method	Field	mm/h
	Calculated (inflow-outflow)	Inflow-outflow	Field	L/s
	Measured (inflow at head)	Syphon	Field	L/s
	Measured (outflow at tail)	Bucket	Field	L/s
	Measured (length of stream head to tail)	Tape	Field	m
	Measured (time of application)	Stopwatch	Field	s

Continues ▶

3.4 Data during Irrigation Events

A surface irrigation event is composed of four phases: advance, ponding, depletion, and recession. To determine the amount of water retained in the soil profile, you must collect specific data during the irrigation process (Table 7). For detailed procedures on analyzing advance and recession processes, refer to *The standard protocols* in FAO, 1989.

Table 7. Data collection on soil infiltration to determine the basic infiltration rate

MD	Measurement date:		
Nature	Soil type [FAO]:	Slope [%]	
	Farm size [ha]:		
Source	Water application methods (furrow, basin, border, ...)		
Location	Northing [UTM]:	Easting [UTM]:	Altitude [masl]:

Parameters measured	Description	Method used	Unit of reporting
Starting time (T_o = 0:00 h)	Measured	Inflow-outflow	l/s
Advance time (T_a = Ti – To)	Measured	Inflow-outflow	l/s
Cutoff time (Tc)		Inflow-outflow	l/s
Recession time (Tr = Ti – Tc)	Measured	Inflow-outflow	l/s
Duration of depletion (Td)	Measured	Inflow-outflow	l/s
Length of point along the furrow	Measured	Inflow-outflow	m
Infiltration opportunity time	Computed: To = Td + Tr	Inflow-outflow	min
Depth of water stored in root zone (depth of moisture)	Computed Use K-L equation $F = K\tau^{\alpha} + f_0 + C$	Inflow-outflow	mm

Note: (1) Ti is the time it takes for the water to reach a specific point of interest in the field after the irrigation starts, measuring how long it takes for the advance front to reach a particular location.

The intake opportunity time, (τ), is the interval during which water will infiltrate at a specified location. It begins when the water flow first reaches the point (advance) and ends when the water eventually drains from the point (recession). Because infiltration is assumed to be uniform over the field, the *variation in intake opportunity time is also an indication of application uniformity*.

3.5 Crop Water Requirement

Based on a substantial amount of research carried out in this field, FAO has developed standard procedures for a range of practical applications in both irrigated and rainfed agriculture. Hence, we used the FAO standard procedure of *FAO Irrigation and Drainage Paper No. 24* to determine the crop water requirement. Procedures and applications for determining water demand and irrigation scheduling are included in the CROPWAT, AQUACROP, and software package using climate data, crop data, and soil data.

Climate data

Climate data essential for agricultural planning include temperature, relative humidity, sunshine hours, wind speed, and monthly rainfall (effective rainfall). You can use data sources from a well-functioning local weather station or an area with a similar agroecological zone. Otherwise, the FAO_Local Climate Estimator (New_LocClim) is an alternative option (https://bit.ly/3Z5N8xa). You could calculate effective rainfall through the CROPWAT or AQUACROP software. Table 8 describes the minimum climate data requirements for these calculations.

Table 8. Climate data collection for irrigation water determination

MD	Measurement date:		
Nature	Soil type, slope:		
Source	Name of meteorological station:		
Location	Northing [UTM]:	Easting [UTM]:	Altitude [masl]:

Parameters measured	Description	Method used	Unit of reporting
Temperature (Max, Min)	Measured/calculated	EMA/FAO Climate Estimator	Degrees centigrade (°C)
Wind speed	Measured/calculated	EMA/FAO Climate Estimator	km/h
Sunshine hours	Measured/calculated	EMA/FAO Climate Estimator	h
Relative humidity	Measured/calculated	EMA/FAO Climate Estimator	%
Rainfall	Measured	Rain gauge/EMA	Mm

Crop data

To collect or measure crop data (crop type, root depth, growth period, planting and harvesting dates) and agronomic data, use the **Guideline for agronomy and soil fertility data collection: national standard**. Crop coefficient (Kc) values could be obtained from locally calibrated values if available or from the *FAO Irrigation and Drainage Paper No. 56*.

Soil data

Soil texture, bulk density, moisture at FC and PWP, allowable moisture depletion level, depth of soil (root depth), and moisture deficit (actual soil moisture content) are the important soil data to be collected (see Table 9).

Table 9. Crop data to be collected for determining crop water demand

MD:	Measurement date [GC]:		
SN:	Name of the scheme:		
FS:	Farm size [ha]:		
Nature:	Soil type, slope:		
Source:	Water application methods: [furrow, ...]		
Location:	Northing [UTM]:	Easting [UTM]:	Altitude [masl]:

Parameters to be measured	Description	Method used	Unit of reporting
Crop variety		Scientific/local name	Scientific name
Root depth (z)	Measured/FAO 56 (1998)	FAO 56 (1998)/local values	cm
Land preparation (LP) Growth period (Gp)	Taken from table/local value	FAO 56 (1998)	Number of days
Planting date (Dp) Harvesting date (Dh)	Recorded	FAO 56 (1998)/FAO CROPWAT	Day of the year in GC (dd/mm/yy)
Crop coefficient (Kc)	Measured/FAO 56 (1998)	FAO 56 (1998)/local values if any	–
Agronomic practice (cost): • Land preparation • Planting/sowing • Harrowing • Seeding • Harvesting	Measured/secondary data Calculated	Number of the agronomic practice times the cost per practice	Birr
Input used: • Seed • Fertilizer • Pesticide, herbicide applied	Calculated Total cost = cost/unit amount * no. units used	Market price	Birr

Continue ▶

Parameters to be measured	Description	Method used	Unit of reporting
Yield (Y)	Measured/calculated	Interview/scheme report	kg

3.6 Pressurized System

Data requirements for determining sprinkler scheme efficiencies are similar to those for surface irrigation, except for two additional parameters: coefficient of uniformity and storage efficiency. For details, refer to *ASABE-S4.361. 2009. Standard engineering practices and data. 56thed. American Society of Agricultural and Biological Engineers. St. Joseph, MI, USA*.

Drip irrigation data specifics include working pressure head, percentage of wetted area, emitter spacing, and emitter discharge rate. See Table 10 for the data required.

Table 10. Data to be collected

Name of the scheme/unit farm:

Location:

Date of data collection:

Parameters	Description	Method	Recording code	Reporting unit
Sprinkler irrigation system				
Irrigation interval (F)	Calculated: $F = \frac{d_n}{CU_p}$	Christianson equation	Field	%
Net depth of irrigation (dn)	Calculated: dn = P(SM)Bd * Rd	FAO 24 (1975), FAO 56 (1998)	Field	mm
Peak consumptive use (CU_p/Eo)	Calculated	FAO CROPWAT/ AQUACROP		mm/day
Command area (A)	Measured	Measuring tape/GPS	Field	ha
Area irrigated per day (a)	Calculated (a = Qs/day)	Measuring tape/GPS	Field	ha
System capacity (Qs)	Calculated: $Q_s = \frac{A \times d}{f \times N_s \times T}$			m^3/s

Continue ▶

Parameters	Description	Method	Recording code	Reporting unit
Gross depth of application mm (d)	Measured	Catch can	Field	mm
Duration of irrigation per shift (T)	Measured	Stopwatch		hr
Duty (D)	Calculated	CROPWAT		m^3/s/ha
No. of shifts (Ns)	Counted	Observation		no.
Irrigation cycle (f)	Calculated: $f = \frac{A}{a}$		Field	day
Drip irrigation system				
Percentage of wetted area (Pw)	Calculated: $P_w(\%) = \frac{N_P * W}{S_L} * 100$			%
Number of emitters (Ne)	Counted	Observation		no.
Width of wetted area (W)	Measured	Meter		m
Spacing between laterals (SL)	Measured	Meter		m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4 Evaluation of Irrigation Water Management

The efficiency of irrigation water use varies from scheme to scheme. Irrigation scheme performance can be evaluated with internal and/or external performance indicators. Internal indicators relate performance to internal management targets, while external indicators enable comparison between different schemes (Ghosh et al., 2005; Molden et al., 1998).

4.1 Internal Performance Indicators

Internal performance describes the effectiveness of the physical system and operating decisions to deliver irrigation water from a water source to the crop. These include conveyance system and field application system efficiency (Irmak et al., 2011). Internal indicators enable a comprehensive understanding of the processes that influence water delivery service and the overall performance of a system (Renault et al., 2007). Table 11 lists the indicators to be computed and the respective minimum data required.

Table 11. Internal performance indicators

MD	Measurement date:		
Nature	Crop type, soil:		
SN	Scheme name:		
SS	Scheme size:		
Source	Water application methods [furrow, ...]:		
Location	Northing [UTM] :	Easting [UTM] :	Altitude [masl] :

Continue ▶

Parameter	Description	Method	Recording protocol	Reporting unit
Conveyance efficiency (Ec)	Ec = water delivered/water diverted	Flow measurement: Table 1	Field	%
Application efficiency (Ea)	Ea = water stored in root zone/water applied	Tables 7 and 8	Field	%
Project efficiency (Eo)	Eo = Ec × Ea	Calculated		%
Distribution uniformity (DU)	DU = average of low quarter depth/mean average depth	Infiltration and soil moisture	Field	%
DP R (deep percolation ratio)	DPR = 100 - Ea - RR		Field	%

Note: Water stored in the root zone can also be obtained from a soil moisture test before and after irrigation.

M_{ai} = moisture content of the i^{th} layer of the soil after irrigation on a weight basis, %.

M_{bi} = moisture content of the i^{th} layer of the soil before irrigation on a weight basis, %.

BD^i = bulk density of the soil in the i^{th} layer.

D_i = soil depth of the i^{th} layer.

RR ranges from 0 for the closed-end system to RR = measured at the outlet.

4.2 External Performance Indicators

External or comparative performance indicators assess the outputs derived from inputs in an irrigated agricultural system (Molden et al., 1998). These indicators provide insights into the overall health of irrigation systems and are designed to be relatively simple to use regularly.

The key categories of external (comparative) indicators are agricultural output, water supply, and delivery capacity, along with financial and physical indicators.

- **Agricultural output indicators:** output per cropped area, output per command area, output per unit irrigation supply, and output per unit water consumed.
- **Water supply indicators:** relative water supply and relative irrigation supply.
- **Delivery capacity:** related to water conveyance efficiency.
- **Physical indicators:** irrigation ratio (IR) and sustainability of irrigated area.
- **Financial indicators:** gross revenue on investment and financial self-sufficiency.

For detailed equations for these indicators, please refer to Molden et al. (1998). Table 12 outlines the data required to calculate these comparative performance indicators.

Table 12. Data required to compute comparative performance indicators

MD	Measurement date:		
Nature	Crop type, soil:		
Source	Water application methods [furrow, ...]:		
Location	Northing [UTM] :	Easting [UTM] :	Altitude [masl] :

Parameters to be measured	Measuring method	Reporting unit
Crop type cultivated	Identified (observation)	Name (local/scientific)
Area for respective crop type	Measured	ha
Production	Measured	kg
Irrigated cropped area	Measured	ha
Command area	Measured	ha
Current irrigated area	Measured	ha
Designed irrigated area	Measured	ha
Diverted irrigation supply	Measured (Q)	m^3
Volume of water consumed	Computed (ETc * A * T)	m^3
Crop demand	Measured	m^3
Irrigation demand	Calculated (FAO CROPWAT)	m^3
Canal supply capacity	Measured	m^3
Peak consumption demand	ETo (FAO CROPWAT)	m^3
Price of each crop	Inventory	Birr
Price of base crop	Inventory	Birr
Price in world market of base crop	Inventory	Birr

5 Minimum Agricultural Drainage Management Data

5.1 Irrigated Land Drainage

Agricultural drainage is the removal and disposal of excess water from irrigated agricultural land. Sources of excess water include precipitation, irrigation water, overland flow or underground seepage from adjacent areas, floodwater from channels, or water applied to manage soil salinity or to control temperature. The amount of water to be removed by such systems depends on the relative effectiveness of the natural and constructed drainage system. Table 13 contains the relative data and parameters.

Table 13. Data to be collected for farm irrigation drainage systems

MD	Measurement date:			
SN	Scheme name:			
SS	Scheme size [ha]:			
Nature	Crop type:			
Soil	Soil type:			
Source	Drain type [surface subsurface]			
Location	Northing [UTM] :	Easting [UTM] :	Altitude [masl] :	
Parameter	**Description**	**Method**	**Recording protocol**	**Reporting unit**
Drain coefficient (q)	Calculated: q = (CL + FL) % + RF + LR		Field	mm/d

Continue ▶

Parameter	Description	Method	Recording protocol	Reporting unit
Conveyance loss (CL)	Calculated	FAO 24 (1975)	Field	%
Field application loss (FL)	Calculated: FL = (GIR – NIR)		Field	mm/ irrigation
Monthly rainfall (RF)	Measured	Rain gauge	Field	mm/ month
Leaching requirement (LR)	Calculated: $LR = \frac{EC_w}{5EC_e - EC_w}$		Field	mm/ irrigation
Discharge: at drain junctions	Calculated: Q = q * A		Field	m^3/s
Discharge: at outfall	Measured or calculated discharge: $Q = \left(\frac{2}{3}\right)^{\frac{3}{2}} b\sqrt{(g)}H^{\frac{3}{2}}$	Broad-crested weir [H is head above the crest and d is the bed width]	Field	m^3/s
	H = head over crest	Measured	Field	m
	b = crest width	Measured	Field	m
	Calculate the discharge: $Q = \left(\frac{2}{3}\right)^{\frac{3}{2}} C_d C_v b\sqrt{g}h^{\frac{3}{2}}$ $C_d = \left(1 - \frac{0.006L}{b}\right)\left(1 - \frac{0.003L}{h}\right)^{\frac{3}{2}}$	Rectangular-throated flume	Field	m^3/s

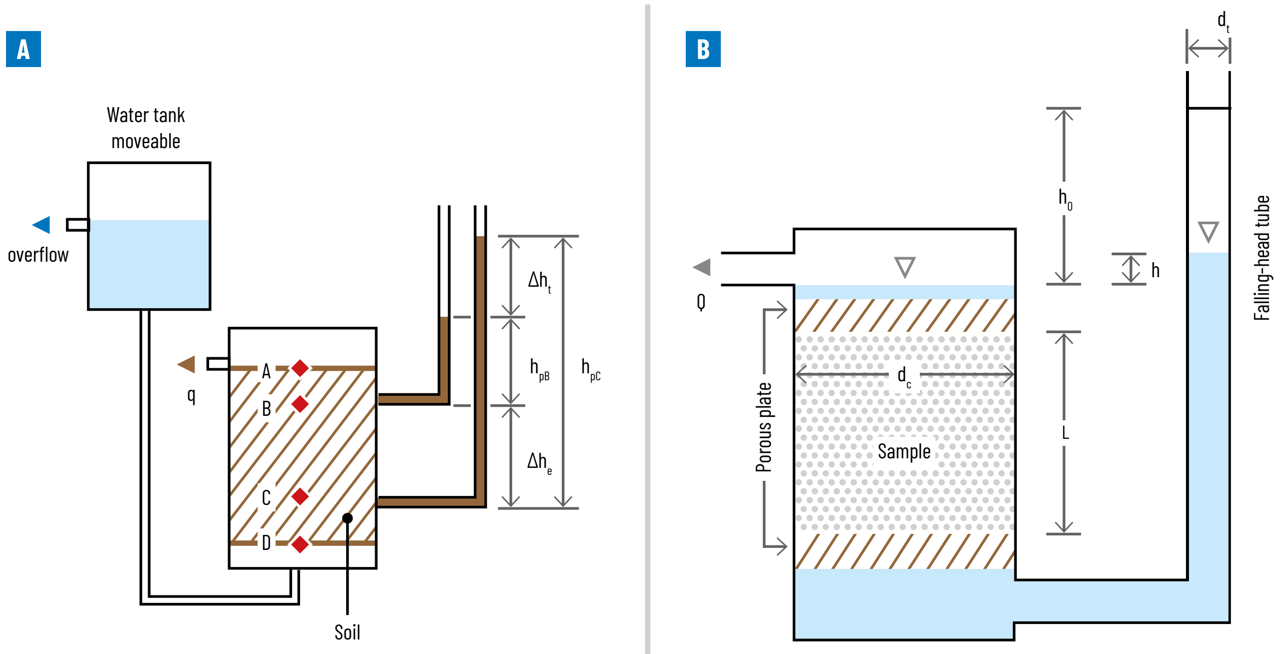
5.2. Hydraulic Conductivity

Soil hydraulic conductivity is a parameter used to determine the flow of water in porous media (soil). Soil hydraulic conductivity is measured either by constant or the falling head method (Table 14 and Figure 3). For details, refer to *Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter* (ASTM D5084-16a). This guideline focuses on saturated hydraulic conductivity, which is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient.

Table 14. Data collected to determine soil permeability

MD	Measurement date [GC]:			
NS	Name of the scheme:			
TC	Type of crop irrigated:			
SS	Farm size [ha]:			
Nature	Soil type, slope:			
Location	Northing [UTM]: Easting [UTM]: Altitude [masl]:			
Parameter	**Description**	**Method**	**Recording protocol**	**Reporting unit**
Discharge (Q)	Measured	Measuring cylinder		m^3/s
Δh_e	Measured	Constant head		m
Δh_t	Measured	Constant head		m
Pipette area (a)	Calculated: $\left[a = \pi \frac{d_t^2}{4}\right]$	Falling head		m^2
Initial hydraulic head (ho)	Measured	Falling head		m
Final hydraulic head (h)	Measured	Falling head		m
Porous media thickness (L)	Measured	Falling head		m
Time (t)	Measured	Falling head		s
K (coefficient of permeability)	Calculated: $k = \frac{\Delta h_e Q}{\Delta h_t \pi R^2}$	Constant head	Lab	cm/h
	Calculated: $K = 2.3 \frac{aL}{31.65t} \times log_e \frac{h_o}{h} = \frac{aL}{13.67t} \times log_{10} \frac{h_o}{h}$	Falling head	Lab	cm/h

Figure 2. Hydraulic conductivity test apparatus setup: (a) constant head, (b) falling head



5.3. Performance Assessment Criteria for a Drainage Scheme

Field drainage structures are designed to remove excess water from a specific area. Common sources of excess water are precipitation, over-irrigation, and extra water needed to manage soil salinity.

Calculating the drainage coefficient of an area depends on watershed characteristics, particularly those related to storms. For irrigated fields, the drainage coefficient can be computed using the Cypress Creek equation (NRCS, 1998). This equation uses the maximum rainfall over 24 hours with a 5-year return interval.

The International Commission on Irrigation and Drainage (ICID) working group has identified depth to groundwater, flooding impact, and drainage system salinity ratio as important indicators in drainage system performance (Bos, 1997). Table 15 outlines specific data required to assess drainage system performance.

Table 15. Data required to compute drainage system performance

MD	Measurement date [GC]		
NS	Name of the scheme		
TC	Type of crop irrigated		
SS	Scheme size [ha]		
Nature	Soil type, slope		
Source	Water application methods (furrow, ...)		
Location	Northing [UTM]:	Easting [UTM]:	Altitude [masl]:

Continue ▶

Parameter	Description	Method	Recording protocol	Reporting unit
Drainage coefficient (q)	Calculated: $q = 0.21 + 0.00047P_{24}$	CIA	Field	mm/d
Maximum daily rainfall (P24)	Measured	Rain gauge		mm
Depth to groundwater (D)	Calculated: $D = \frac{Dt - Do}{Do}$		Field	%
Initial depth to groundwater (Do)	Measured	Piezometer		m
Depth to GW at time t (Dt)	Measured	Piezometer		m
Impact of flooding (IF)	Calculated: $IF = \frac{Af}{Air}$			%
Flooded irrigated area (Af)	Measured	Meter		ha
Total irrigated area (Air)	Measured	Meter		ha
System drainage ratio	Calculated: $DR = \frac{Dt}{Da}$			%
Drained volume (Dt)	Measured	Partial flume		m^3
Actual delivered volume (Da)	Measured			m^3
Relative change in EC	Calculated: $EC\_R = \frac{ECt}{ECi}$			%
Initial EC (Eci)	Measured	EC meter		Ds/cm
Current EC (ECt)	Measured	EC meter		Ds/cm

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Annex

Table A. Dimensions of standard Parshall flumes (source: Asawa, 2008)

Parshall flume dimensions (mm)																		
b (Throat width)		A	a	B	C	D	E	L	G	H	K	M	N	P	R	X	Y	Z
	mm																	
1 in	25.4	363	242	356	93	167	229	76	203	206	19	-	29	-	-	8	13	3
2 in	50.8	414	276	406	135	214	254	114	254	257	22	-	43	-	-	16	25	6
3 in	76.2	467	311	457	178	259	457	152	305	309	25	-	57	-	-	25	38	13
6 in	152.4	621	414	610	394	397	610	305	610	-	76	305	114	902	406	51	76	-
9 in	228.6	879	587	864	381	575	762	305	457	-	76	305	114	1080	406	51	76	-
1 ft	304.8	1372	914	1343	610	845	914	610	914	-	76	381	229	1492	508	51	76	-
1.5 ft	457.2	1448	965	1419	762	1026	914	610	914	-	76	381	229	1676	508	51	76	-
2 ft	609.6	1524	1016	1495	914	1206	914	610	914	-	76	381	229	1854	508	51	76	-
3 ft	914.4	1676	1118	1645	1219	1572	914	610	914	-	76	381	229	2222	508	51	76	-
4 ft	1219.2	1829	1219	1794	1524	1937	914	610	914	-	76	457	229	2711	610	51	76	-

Continue

Parshall flume dimensions (mm)

b (Throat width)		A	a	B	C	D	E	L	G	H	K	M	N	P	R	X	Y	Z
	mm																	
5 ft	1524	1981	1321	1943	1829	2302	914	610	914	-	76	457	229	3080	610	51	76	-
6 ft	1828.8	2134	1422	2092	2134	2667	914	610	914	-	76	457	229	3442	610	51	76	-
7 ft	2133.6	2286	1524	2242	2438	3032	914	610	914	-	76	457	229	3810	610	51	76	-
8 ft	2438.4	2438	1626	2391	2743	3397	914	610	914		76	457	229	4172	610	51	76	-
10 ft	3048	-	1829	4267	3658	4756	1219	914	1829	-	152	-	343	-	-	305	229	-
12 ft	3658	-	2032	4877	4470	5607	1524	914	2438	-	152	-	343	-	-	305	229	-
15 ft	4572	-	2337	7620	5588	7620	1829	1219	3048	-	229	-	457	-	-	305	229	-
20 ft	6069	-	2845	7620	7315	9144	2134	1829	3658	-	305	-	686	-	-	305	229	-
25 ft	7620	-	3353	7620	8941	10668	2134	1829	3962	-	305	-	686	-	-	305	229	-
30 ft	9144	-	3861	7925	10566	12313	2134	1829	4267	-	305	-	686	-	-	305	229	-
40 ft	12192	-	4877	8230	13818	15481	2134	1829	4877	-	305	-	686	-	-	305	229	-
50 ft	15240	-	5893	8230	17272	18529	2134	1829	6096	-	305	-	686	-	-	305	229	-

Table B. Discharge characteristics of Parshall flumes (source: Asawa, 2008)

Discharge characteristics of Parshall flumes						
Throat width, b	Discharge range (l/s)		Equation $Q=kh_1^n$ (h_1 is in m & Q is in m^3/s)	Head range, m		Modular limit, h_2/h_1
	Minimum	Maximum		Minimum	Maximum	
1 in	0.09	5.4	$Q=0.0604h_1^{1.55}$	0.015	0.21	0.5
2 in	0.18	13.2	$Q=0.1207h_1^{1.55}$	0.015	0.24	0.5
3 in	0.77	32.1	$Q=0.1771h_1^{1.55}$	0.03	0.33	0.5
6 in	1.5	111	$Q=0.3812h_1^{1.58}$	0.03	0.45	0.6
9 in	2.5	251	$Q=0.5354h_1^{1.53}$	0.03	0.61	0.6
1 ft	3.32	457	$Q=0.6909h_1^{1.52}$	0.03	0.76	0.7
1.5 ft	4.8	695	$Q=1.056h_1^{1.538}$	0.03	0.76	0.7
2 ft	12.1	937	$Q=1.428h_1^{1.55}$	0.046	0.76	0.7
3 ft	17.6	1427	$Q=2.184h_1^{1.556}$	0.046	0.76	0.7
4 ft	35.8	1923	$Q=2.953h_1^{1.578}$	0.06	0.76	0.7
5 ft	44.1	2424	$Q=3.732h_1^{1.587}$	0.06	0.76	0.7
6 ft	74.1	2929	$Q=4.519h_1^{1.595}$	0.076	0.76	0.7
7 ft	85.8	3438	$Q=5.312h_1^{1.601}$	0.076	0.76	0.7
8 ft	97.2	3949	$Q=6.112h_1^{1.607}$	0.076	0.76	0.7
	m^3/s					
10 ft	0.16	8.28	$Q=7.463h_1^{1.6}$	0.09	1.07	0.8
12 ft	0.19	14.68	$Q=8.859h_1^{1.6}$	0.09	1.37	0.8
15 ft	0.23	25.04	$Q=10.96h_1^{1.6}$	0.09	1.67	0.8
20 ft	0.31	37.97	$Q=14.45h_1^{1.6}$	0.09	1.83	0.8
25 ft	0.38	47.14	$Q=17.94h_1^{1.6}$	0.09	1.83	0.8
30 ft	0.46	56.33	$Q=21.44h_1^{1.6}$	0.09	1.83	0.8
40 ft	0.6	74.7	$Q=28.43h_1^{1.6}$	0.09	1.83	0.8
50 ft	0.75	93.04	$Q=35.41h_1^{1.6}$	0.09	1.83	0.8

Table C. Recommended limits for constituents in reclaimed water for irrigation (In Fipps, 2003 .Adapted from Rowe and Abdel-Magid, 1995)

Constituent	Long-term use (mg/L)	Short-term use (mg/L)	Remarks
Aluminum (Al)	5.0	20	Can cause non-productivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic (As)	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium (Be)	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron (B)	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/L. Most grasses relatively tolerant at 2.0 to 10 mg/L.
Cadmium (Cd)	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.
Chromium (Cr)	0.1	1.0	Not generally recognized as essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt (Co)	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper (Cu)	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride (F-)	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron (Fe)	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead (Pb)	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium (Li)	2.5	2.5	Tolerated by most crops at up to 5 mg/L; mobile in soil. Toxic to citrus at low doses recommended limit is 0.075 mg/L.

▼ Continue

Constituent	Long-term use (mg/L)	Short-term use (mg/L)	Remarks
Manganese (Mg)	0.2	10.0	Toxic to a number of crops at few-tenths to a few mg/L in acid soils.
Molybdenum (Mo)	0.01	0.05	Nontoxic to plants at normal concentrations in soil and water can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel (Ni)	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium (Se)	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of added selenium.
Vanadium (V)	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc (Zn)	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.